Table 13

Annual EMERGY Flows in the Mangrove Nursery System of Ecuador.
119,500 Hectares. See Figure 17.

Note	Item	Raw Units J,g,$		Transformity Sej/unit	Solar EMERGY E18 sej/yr	Macroeconomic 1989 US E6 $/yr
1	Solar energy	4.4 E+18	J	1	4.44	2.22
2	Wind energy	4.4 E+14	J	623	0.27	0.14
3	Mangrove transpiration	4.4 E+15	J	41068	179.06	89.53
4	Rain chemical potential	5.2 E+15	J	15444	80.31	40.15
5	Tides	4.2 E+15	J	23564	99.91	49.96
6	Total solids from sewer	5.8 E+10	J	62400	0.00	0.00
7	Total N from sewers	4.2 E+08	g	9.0 E+08	0.38	0.19
8	Total P from sewers	5.15 E+07	g	8.1 E+09	0.42	0.21
9	Biomass growth	1.9 E+16	J	14684	279.00	139.50
10	Litterfall	2.1 E+16	J	13285	278.99	139.49
11	Shrimp produced	2.1 E+12	J	2000000	4.20	2.10
12	Independent total	—		—	278.97	139.48

Footnotes for Table 13

1. Solar input: 1195 E6 m2, 127 kcal/cm-yr average solar insolation.
(1195 E6 m2)(127 E4 kcal/m2-yr)(.7 absorbed)(4186 J/kcal) = 4.44 E18 J/yr.

2. Wind energy: 0.19 available inshore system (areal ratio) - see Table 12, note #2.

3. Mangrove transpiration:
(2.5 mm/d)(365 d/yr)(1000 g/mm/m2)(4.0 J/g)(1195 E6 m2) = 4.36 E15 J/yr

4. Rain chemical potential energy: Av. precipitation in Guayaquil 885 mm/yr (Twilley, 1986): (1195 E6 m2)(.885 m)(1 E6 g/m3)(4.94 J/g) = 5.2 E15 J/yr.

5. Tidal energy range absorbed in mangroves, 1.0 m;
(706/yr)(9.8 m/s2)(1.025 E3 Kg/m3)(11.195 E9 m2)(1.0 M)(1.0m) = 4.23 E15 J/yr

6. Total suspended solids in sewer effluent: 6456 E6 g/yr. 0.2 of area;
(0.2)(6456 E6 g)(.002 organic)(5.4 kcal/g)(4186 J/kcal) = 5.84 E10 J/yr.

7. Nitrogen concentration in sewer effluent 2.1 E9 g/yr; 0.2 of estuary area (Twilley, 1986).
(2.1E9)(.2) = 4.2E8 g/yr

8. Phosphate concentration in sewer effluent 2.58 E8 g/yr (Twilley, 1986); 0.2 area. (2.58 E8 g/yr)(.2) = 5.15 E7 g/yr

9. Mangrove biomass growth: 2.8 g/m2-day (observation from Snedaker, 1986 and Sell, 1977).
(1195 E6 m2)(2.8g/m2-d)(365 d)(3764 cal/g)(4.186 J/cal) = 1.9 E16 J/yr.
Transformity:(279 E18 sej/yr in footnote 12)/(1.9 E16 J/yr) = 14684 sej/J.

10. Mangrove litter fall: 957 - 1032 g/m2-yr (Sell, 1977); av. 995 g/m2-yr. (995 g/m2)(1195 E6 m2)(4139 cal/g)(4.186 J/cal) = 2.1 E16 J/yr.
Transformity: (279 E18 sej/yr)/(2.1 E16 J/yr) = 13285 sej/J

11. Medium sized shrimp produced (70 individuals-tails per pound) Turner(1985): 10 kg commercial yield of adults per hectare of vegetated nursery.
(10 kg/ha)(2.2 lb/kg)(.7 tails)(35 tails/lb) = 539 individuals/Ha
(539 ind./ha)(1195 E6 m2)(/70 ind/lb)/(1 E4 m2/ha) = 9.2 E5 lb
(9.2 E5 lbs)(.2 dry)(454 g/lb)(6.0 kcal/g)(4186 J/kcal) = 2.1 E12 J/yr
Transformity for estuarine shrimp, half of larger offshore adults:
(0.5)(4 E6 sej/J in Table 15) = 2 E6 SEJ/j

12. Total omitting double counting: sum of transpiration and tide:
(179 + 100) = 279 E18 sej/yr

Table 14a.
Annual EMERGY Flows of Shrimp Pond Mariculture in Ecuador, 1986
53,000 Hectares; 1.5 m deep; see system diagram in Figure 5.

Note	Item	Raw Units J,g,$		Transformity Sej/unit	Solar Emergy E20	Macroeconomic US $E6
1.	Sunlight	1.97 E18	J	1	0.0197	0.99
2.	Rain	2.65 E15	J	15444	0.41	20.5
3.	Pumped sea waters	7.33 E15	J	15444	1.1	55.
4.	Post larvae	3.2 E9	ind	1.04 E11	3.4	170.
	Sum of Free inputs, direct sun omitted				4.92	246
5.	Labor	1.32 E14	J	2.62 E6	3.79	189.
6.	Fuel	2.34 E15	J	5.3E4	1.24	62.
7.	Nitrogen fertilizer	1.14 E9	g	4.19 E9	0.048	2.4
8.	Phosphorus fertiliz.	2.62 E8	g	2.0 E10	0.053	2.6
9.	Feed protein	3.29 E15	J	1.31 E5	4.3	215.
10.	Other services	3.56 E7	$ US	8.5 E12	3.0	151.
11.	Costs of post-larvae	3.56 E7	$ US	8.7 E12	3.0	151.
12.	Capital costs	1.93 E6	$ US	8.5 E12	0.164	8.2
13.	Interest paid back in sucres or sucre-converted-to $					
		11.2 E6	$ US	8.5 E12	.95	47.6
	Sum of Purchased Inputs				16.9	845
	Sum without organic feed				12.7	635
	Sum of all Inputs				21.82	1092
	Sum without organic Feed				17.6	880
14.	Shrimp yield using organic feed					
	Efficient value	1.68 E14	J	4.0 E6	6.72	336
	Resource used	1.68 E14	J	13.0 E6	21.80	1092
15.	Shrimp yield without organic feed					
	Efficient value	0.93 E14	J	4.0 E6	3.72	186
	Resource used	0.93 E14	J	18.9 E6	17.58	879

Table 14b. Indices from Table 14a

EMERGY investment ratio:
With organic feed = (16.9 E20 sej/yr)/(4.92 E20 sej/yr) = 3.4
Without organic feed = (12.7 E20 sej/yr)/(4.92 E20 sej/yr) = 2.6
For comparison, regional EMERGY investment ratio = 2.3

Solar transformity of Shrimp from shrimp ponds:(Input EMERGY)/(yield energy)
= (21.82 E20 sej/yr)/(1.68 E14 J) = 13.0 E6 sej/J.
Solar transformity in ponds without organic feed
= (17.6 E20 sej/yr)/(9.3 E13 J) = 18.9 E6 sej/J.
For comparisons, Peneid shrimp transformities elsewhere = 4 - 8 E6 sej/J (Table 15).

Net EMERGY yield ratio (Yield EMERGY/Purchased EMERGY):
With organic feed = (21.82 E20 sej/yr)/(16.9 E20) = 1.3
without organic feed = (17.6 E20)/(12.7) E20) = 1.4

EMERGY amplifier ratio explained in Figure 11; using an average transformity before and after amplifying production, 16 E6 sej/J.

EMERGY increase due to feeding with fish meal
16.0 E6 sej/J * (1.68 -.93) E14 J/yr

EMERGY in added fish meal (Table 14a)

$$\text{amplifier ratio} = \frac{12.0\ \text{E20 sej/yr}}{4.3\ \text{E20 sej/yr}} = 2.8$$

Footnotes for Table 14a

1. Direct solar energy:
(127 E4 kcal/m2/yr)(4186 J/kcal)(0.7 absorbed)(530 E6 m2) = 1.97 E18 J/yr
2. Rain into ponds:(1 m/yr)(530 E6 m2)(1 E6 g/m3)(5 J/g) = 2.65 E15 J/yr
3. Pumped sea water to maintain water levels and salinity; evaluated freshwater content:
(0.1 vol/d)(365 d)(1.5m)(5.38E5 m2)(.08 fresh)(1E6 g/m3)(3 J/g)=7.4 E15 J/yr
4. Input of post-larvae estimated from pond yield 3.0E4 tonne (Aquacultura de Ecuador, 1988):
(30 E6 kg)(2.2 lbs/kg)(.70 tails))(35 tails/lb)/(.5 mortality) = 3.2 E9 ind./y
Larvae can be thought about as information packages with little energy. When a shrimp releases many larvae, this represents a split of the EMERGY. Each tiny new individual carries an information copy. If the population is at steady state the larvae grow and are depleted in number by mortality eventually replacing two adults. This is a closed life cycle dependent on all the inputs necessary for the whole sequence. The EMERGY per individual is a transformity that grows reaching a maximum with the reproducing individuals. For a mortality commensurate with growth of the surviving, post-larvae with 50% further mortality represents 2 individuals that will finally restore 1 adult. Thus a transformity for the post-

larvae is half that of the reproducing adult before harvest (.5 * 4 E6 sej/J). On an individual basis the solar transformity is:
(0.5)(4 E6 sej/J)(10 g/ind)(.2 dry)(6.2 kcal/g)(4186 J/kcal) = 1.04 E11 sej/ind

5. Transformity of Labor in Ecuador estimated as national EMERGY/person/yr from Table 6.
Energy/person = (2500 kcal/d)(365 d/yr)(4186 J/kcal)(4186 J/kcal) = 3.82 E9 J/yr.
Solar transformity = (10 E15 sej/ind/yr)/(3.82 E9 J/ind/yr) = 2.62 E6 sej/J
90,000 fisherman 5 days a month; 20,000 people full time
(12.7 E6 person-days)(2500 kcal/person-day)(4186 J/kcal) = 1.32 E14 J/yr

6. Fuel: estimated as a percent of operating cost of pumped pond; price (Aquacultura del Ecuador, 1988):
($.10/lb shrimp)(26.4 E6 kg/yr)(2.2 lbs/kg)/($.34/gal fuel) = 17 E6 gal//yr
(17.1 E6 gal/yr)(137 E6 J/gallon) = 2.34 E15 J/yr

7. Nitrogen fertilizer for each 6 month start; 1.3 g/m3 N;
Volume: (1.5 m deep)(2.91 E8 m2) = 4.365 E8 m3
(4.365 E8 m3)(1.3 g/m3)(2/yr) = 1.135 E9 g/yr

8. Phosphorus fertilizer for each 6 month start: 0.3 g/m3;
(4.365 E8 m3)(0.3 g/m3)(2/yr) = 2.62 E8 g/yr

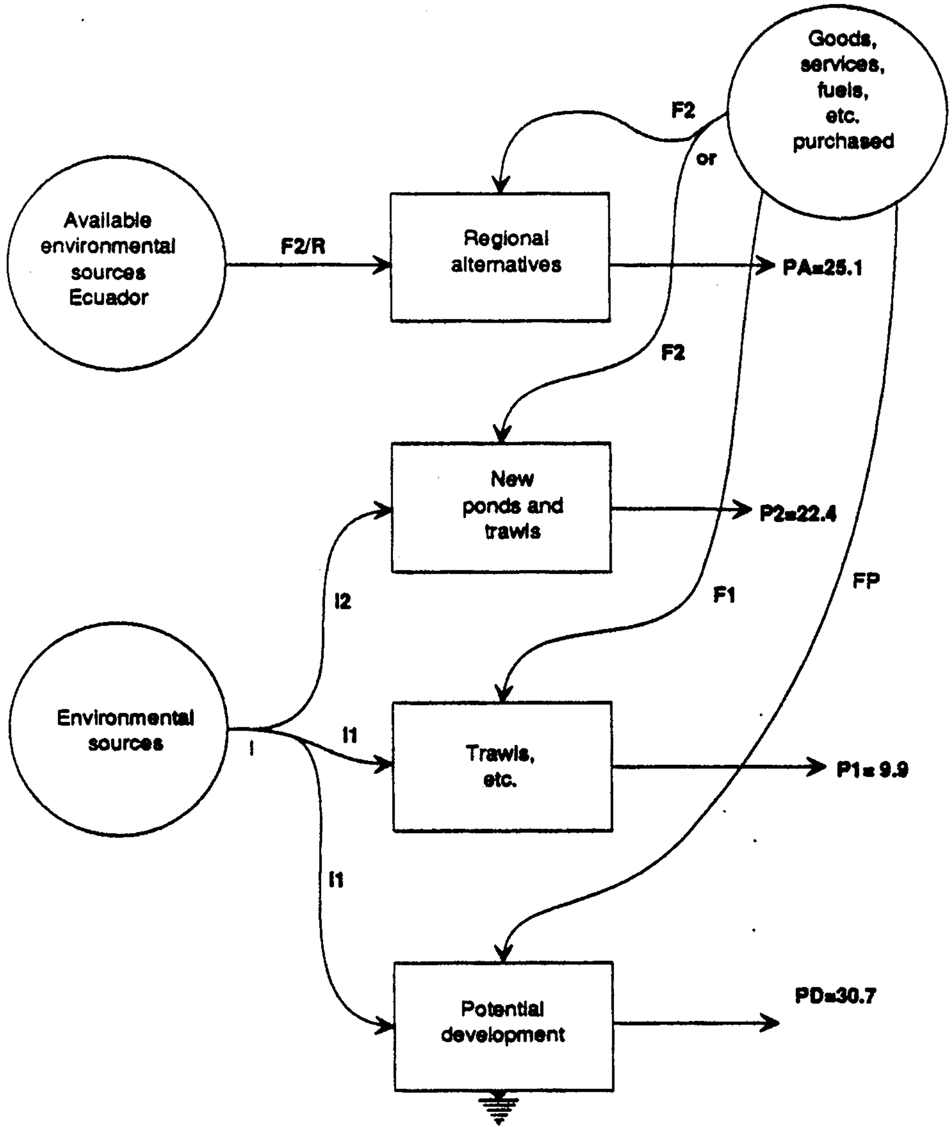
9. Feed; Fish meal from offshore herring, sardines; See text figure.
Total feed = sum of 23,600 Ha of semi-extensive ponds, fed for last 60 days.
(45 kg/ha/d)(1 E3 g/kg)(2.36 E4 ha)(60 d)(5.7 kcal/g)(4186 J/kcal) = 1.52 E15 J /yr
and 5500 Ha of semi-intensive ponds, fed for 300 days:
(45 kg/ha/d)(1 E3 g/kg)(5500 ha)(300 d)(5.7 kcal/g)(4186 J/kcal) = 1.77 E15 J/yr
Total feed supplement: (1.52 + 1.77 = 3.29 E15) J/yr
Much of the fish meal came from herring, sardines, etc mostly beyond the continental shelf. A solar transformity was estimated using organic carbon per square meter in herring sardines and anchovettas yield from the pelagic upwelling system published by Walsh (1981) divided by the solar EMERGY of the current. EMERGY of direct solar energy, and chemical energy of rain were also evaluated, but were less than the physical energy of the Humboldt current. As lesser by products of the world weather system direct sun and oceanic rain were omitted to avoid double counting.
Fish yield was 6.71 grams Carbon/m2/year with energy content:
(6.71 g C/m2/yr)(2.5 g org./g C)(5.7 kcal/g)(4186 J/kcal) = 4.00 E5 J/m2/yr.
Solar Emergy input per square meter of pelagic ecosystem generating this meal includes direct sun, rain, and the physical energy being used from the several sources driving the Humboldt current, the waves, and upwelling. The circulation of the east Pacific gyral includes wind energy transferred from the large scale circulation of the atmosphere wind plus large scale pressure gradients maintained by density differences due to temperatuare and salinity differences. In this pelagic system unlike the inshore ones, the tidal absorption and river contrtibutions are less. The physical energy was estimated by assuming a fraction of 1% of the kinetic energy used up per day in steady state with the sources. As the calculations below show, the EMERGY of the direct sun and direct rain are small by comparison.
EMERGY of direct solar Energy under offshore stratus::
(1 m2)(1.00 E6 kcal/m2/yr)(4186 J/kcal)(1 sej/J) = 4.19 E9 sej/m2/yr

Physical energy (tentative pending better sources);
(0.5)(.3 m/sec)(.3 m/sec)(100 m deep)(1 m2)(1025 kg/m3)(.01/day)(365 d/yr)
= 1.68 E4 J/m2/yr physical energy
EMERGY flux using solar transformity of river current at New Orleans: (4.67 E4 J/m2/yr)(80 E5 sej/J) = 1.34 E11 sej/m2/yr
Rainfall chemical energy on the open sea:
The solar transformity of rain falling over the ocean is different from that over land. Land is at a higher level in the geological hierarchy in which the solar energy falling on the seas is part of the basis for converging atmospheric processes to interact with continent building processes to generate rain on land. Solar transformity of rain over land was calculated as the quotient of the earths annual EMERGY divided by the Gibbs free energy of the rain over land relative to sea water. Rain over the sea is a necessary by-product feedback lower in the hierarchy with larger volume for the same earth EMERGY budget. Rain over ocean was assumed 71/29 of 1.05 E14 m3/yr rain over land in proportion to the ocean/land areas.

$$\text{Solar transformity of oceanic rain} \quad \frac{8.1\text{ E }24\text{ sej/yr/earth}}{(2.57\text{ E14 m3/yr})(1\text{ E6 g/m3})(4.94\text{ J/g})} = 6380\text{ sej/J}$$

(1.0 m)(1 m2)(1 E6 g/m3)(4.94 J/g) = 4.9 E6 J/m2/yr
Solar Emergy: (4.9 E6 J/m2/yr)(6380 sej/J) = 3.13 E10 sej/m2/yr
Solar transformity of the fish meal based on 1 m2 of pelagic offshore; see Figure. EMERGY sum (1.34 +. 014 = 1.35) E11
(5.24 E10 sej/m2/yr)/(4.00 E5 J/m2) fish meal = 1.31 E5 sej/J
Costs (services) of feed supplement for 1986 from Camara de Productores de Camaron (1989)
EMERGY value added in fishmeal preparation:
(17% cost for supplementary feeding)(150 E6 $) = 25.5 E6 $
(8.7 E12 sej/$)($25.5 E6) - 2.2 E20 sej/yr

10. Operating costs given as $2.70 (1986 U.S. $) per kilogram of shrimp yield.
($2.70 US /kg)(26.4 E6 kg/yr yield) = 71.2 E6 U.S.$;
Half of this is for post larvae (note 11) and half for other services:
(0.5)(71.2 E6 US $) = 35.6 E6 US $.
For evaluating EMERGY, use 8.7 sej/$ within Ecuador calculated in Table 3.
11. Costs of post larvae: 50% of total operating cost (note 10): 35.6 E6 US $.
12. Capital costs: (235 E3 sucre/ha)(2.91 E4 Ha)/(122 sucre/$) = 58 E6 $US
Assume 30 year life of ponds; annual cost = 58 E6 $US/30 yr = 1.93 $US/yr
13. Interest on loans for capital investment at 20% of principal
(.2)(58 E6 $US/30 yr) = 11.6 E6 $US. Whether aid to an investor within Ecuador or one in the U.S., the sucres when converted to international $ represent EMERGY according to the Ecuadorian EMERGY/$ ratio (8.5 sej/$).
14. Yield: 30,000 tonne/yr:
(3.0 E10 g/yr)(0.2 dry)(6.7 kcal/g dry)(4186 J/kcal) = 1.68 E14 J/yr
15. Yield without organic feed: 598 lb/Ha (Camara de productores de Camaron, 1989)
(5.3 E4 Ha)(598 lb/Ha)(454g/lb)(.2 dry)(6.7 Kcal/g dry)(4186 J/kcal)
= 9.28 E13 J/yr



E20 sej/yr

Figure 18. EMERGY benefit comparison of original system with trawls (P1), new system of ponds and trawls (P2), typical alternative investment (PA) and potential development (PD).

		E20 sej/yr
Environmental inputs to trawl fishery (0.227 E20 in Table 12B and environmental later displaced (9.1 E20 in Table 16:		I1 = 9.3
Environmental inputs to ponds (Table 14A, line 1-4):		I2 = 4.92
Purchased inputs to trawl fishery(Table 12a, line 11,12):		F1 = 0.61
Purchased inputs to ponds (Table 14a 16.9) and trawls:		F2 = 17.5
Old shrimp system (trawls and local fishing) :	P1 = I1 + F1	= 9.9
New shrimp system (trawls and ponds)	P2 = I2 + F2	= 22.4
Alternative regional development where investment ratio R = 2.3	PA = F2 + F2/R	= 25.1
Potential development, matching original I1	PD = I1 + I1 * R	= 30.7

Table 16
Change in Annual EMERGY Flows of Coastal System with Shrimp Pond Developments

	Item	Solar EMERGY E20 sej/yr	Macroeconomic $ E6 US 1989 $/yr*
Change in purchased inputs for pond development:			
1	Pond Labor and services added	+9.95	+498.
2	Pond fuel use added	+1.24	+62
3	Debt & profit lost	-0.71	-35.5
Changes in environmental resources to develop shrimp ponds:			
4	Loss of Mangrove area	-0.04	-2.0
5	Lost Areas of organic runoff	-0.22	-11.0
6	Shrimp Post-Larvae diverted	-3.4	-170.
7	Estuarine Waters diverted	-1.1	-55.
8	Fish diverted to feed shrimp	-4.3	-215.
9	Shrimp Trawl decrease	-0.046	-2.34
10	Environmental losses (items 4-9) =	-9.1	-455.
11	Exported pond shrimp =	-21.5	-1075.
12	Purchased gains & losses (items 1,2 & 3) (+10.17+1.24 -.71 E20) =	+10.7	+535
13	Buying power from exported pond shrimp	+7.56	+378
14	Net benefit to the local region: (7.56 +10.7 - 9.1 - 21.5 E20)	-12.04	-602
15	Net benefit to foreign economies: (21.2+.58 -7.56 E20)	+14.2	+710
16	EMERGY increase for the planet (21.2 - 9.1 E20)	+12.1	+600
17	Developed potential (U.S. level)	+9.4	+470
18	Sustainable potential (Long range)	+3.86	+193

Footnotes for Table 16

*Solar EMERGY change in sej/yr divided by 2 E12 sej/U.S. 1989 $

1 Labor, new services, costs of post-larvae, and capital costs in Table 14.
items 5, 10, 11, & 12 (3.79 + 3.0 + 3.0 + 0.164)= 9.95 E 20 sej/yr

2 Fuel, item 6 in Table 14.

3 Interest and profit assumed to leave the local area; item 13, Table 14.

4 Mangrove loss: 6000 hectares; Transpiration rate, 2.5 mm/day
(2.5 mm/d)(365 d/yr)(1000g/m2/mm/d)(4.8 J/g)(6.0 E7 m2 loss)(15444 sej/J)
= 4.05 E18 sej/yr

5 Organic runoff diverted by 46,600 hectares ponds on salterns and other areas contributing organic matter. 1 g/m2/day net production
(1 g/m2/d)(365 d/yr)(4.6 E8 m2 lost)(5 kcal/g) (4186 J/kcal)(6000sej/J) = 0.22 E20 sej/yr

6 Post larvae diverted: item 4 Table 14

7 Estuarine water (its fresh water content) diversion, item 3, Table 14.

8 Shrimp feed, item 9, Table 14.

9 (2000 pounds less/boat-McPadden, 1986)(249 boats) = 498,000 pounds
(4.98 E5 lb/yr)(454 g/lb)(.2 dry)(6.2kcal/g) (4186 J/kcal)(4 E6 sej/J) = 4.68E18 sej/yr.

10 Items 4-9 are losses from the environmental system but transferred for the most part to the pond system, thus being retained in the area. However, their use here is grossly inefficient, generating one fourth of the EMERGY yield compared to the enviromental and purchased inputs utilized. See Table 15.

11 Shrimp pond yield, item 14 Table 14.

12 Interest and profit removes EMERGY, especially if financed from the developed countries with much smaller EMERGY/$ ratio. See section on "Shrimp and International Exchange".

13 Shrimp exports item 2 Table 2. Buying power of US $, with US EMERGY/$ ratio
(315 E6 US $/yr)(2.4 E12 sej/US $ in 1986) = 7.56 E20 sej/yr

14 Buying power earned from shrimp sale plus purchased inputs of EMERGY used minus environmental losses minus the EMERGY of exported shrimp.

15 Benefit to foreign developed economy from shrimp received plus EMERGY of Ecuador's EMERGY/$ value of interest and profit (assuming half financed from developed country) minus purchases made with shrimp earnings.

16 Change in annual rate of EMERGY production and use considered on a world basis without regard to where it goes or is used or where the money goes:
Shrimp Pond production (which includes EMERGY in new fuel use and new items purchased from fuel-based economy (items 1 & 2) and some environmental inputs) minus environmental loss (item 10).

17 Temporary potential to developed economy using investment ratio of 7 (U.S.A.). For calculations in footnote 18.

18 Sustainable contribution was estimated as the sum of the renewable environmental input plus the economic development for the present regional investment ratio 2.3 which is similar to the world ratio.
The environmental EMERGY input(Table 13) per unit coastal area is:
(279 E18 sej/yr)/(1.195 E9 m2) = 2.33 E11 sej/m2/yr

The environmental EMERGY input for the coastal area is calculated as if all that shrimp pond area was calculated as if all converted into tidal mangroves even that which was originally upland.

$$(2.33\ E11\ sej/m2)(5.3\ E8\ m2) = 1.17\ E20\ sej/yr$$

Investment ratio 2.3 multiplied by environmental EMERGY is

$$(2.3)(1.17\ E20\ sej/yr) = 2.69\ E20\ sej/yr)$$

Environmental and sustainable economic matching:

$$(1.17\ E20 + 2.69\ E20\ ) = 3.86\ E20\ sej/yr$$